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The Missing Top: Prospects at the Tevatron

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THE MISSING TOP:

PROSPECTS AT THE TEVATRON

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ABSTRACT

A new run has begun at the Tevatron Collider, and two detectors, CDF and D0, have started taking data. After a short review of the situation of the top search in both the single and dilepton channel, we present the expectations for the near and far future. There have already been accelerator and detector upgrades, and more are to come. Important improvements are also expected from new analysis tools.

1. Review of the top search

At a hadron collider a heavy top is produced in pairs, as $p\bar{p} \rightarrow t\bar{t}X$. In the standard model, the t quark is expected to decay into a b quark and a W boson ($t \rightarrow Wb$). Each W subsequently decays into two quarks or a charged lepton + a neutrino. $t\bar{t}$ events have therefore several different signatures to be exploited for detection. The only signatures which have yielded results so far in the search for a standard model top, are the "single lepton" channel and the "dilepton" channel.
In the single lepton channel we consider events with a W decaying into a charged lepton and a neutrino, accompanied by additional jet activity in the event. CDF used the e+2 jets mode to first rule out top below 77 GeV/c^2 at 95% C.L. [1]. This limit was obtained comparing the transverse mass distribution of the $e + \nu$ system with that expected for a top signal, and for the background (events coming from QCD W+ multi jet production). If $M_{top} < M_W$, the top decays into a virtual W, and we have different transverse mass distributions for signal and background (real W's).
In the dilepton analysis CDF studied the ee, $e\mu$, $\mu\mu$ channels. Events with two high P_t (> 15 GeV) isolated leptons of opposite charge, missing E_t and jets were selected. Topological cuts were added to reject the background due to Drell Yan, $b\bar{b}$ production and to the dilepton decay of the Z^0. After imposing these cuts one $e\mu$ event is left. No dielectron or dimuon events remained in the data (see figure 1). The analysis was later extended to include events with one large P_t lepton from W decay and one soft muon from beauty decay. For top masses not too much greater than the W mass, the two most energetic jets in the event usually come from the hadronic decay of the W's. We therefore required that the soft muon should not be near to the two highest energy jets. No additional top candidates were found. In order to get a limit on the top mass, we assumed the only $e\mu$ event found to be top. Taking this one event into account, the analysis was able to arrive at a limit

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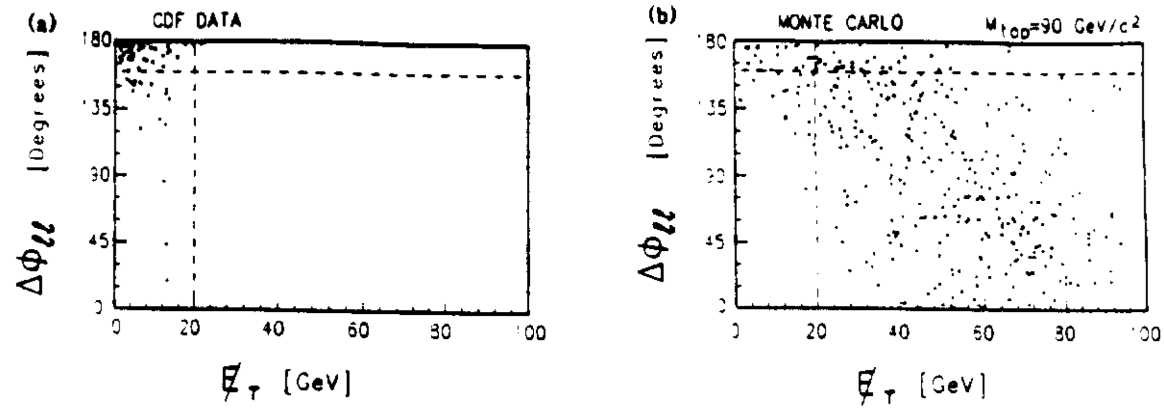

Figure 1: Distribution of missing E_t vs. $\Delta\phi_{ll}$ (asimuthal angular separation between the two leptons). (a) CDF dielectron and dimuon data for 4.1 pb^{-1}. (b) Montecarlo $t\bar{t}\rightarrow ll+X$ events for M_{top}=90 GeV/c^2 for 600 pb^{-1}. There are no events in the signal region bejond the dashed lines

of M_{top}>91 GeV/c^2 at 95% C.L. [2].

2. The 1992 run and beyond

Fermilab has an ambitious Tevatron improvement program, which will upgrade its performance and extend its physics reach during the coming years. Two $p\bar{p}$ collider experiment are now operational at the Tevatron: CDF and the new detector D0.

2.1. *The upgraded CDF detector*

The CDF detector has undergone several upgrades, with respect to the 88–89 run [3]. Some of them were required in view of its operation at higher luminosity and others to improve its physics capability by extending the covered kinematic region and by increasing the detector's resolving power and background rejection. The central muon upgrade will improve rejection of hadron punch-throughs in the region already covered ($0<|\eta|<0.7$). The muon coverage is now extended to the region $0.7<|\eta|<1.1$. The cause of glow discharges at the edge of the plug gas calorimeters has been identified and repaired. In this way the coverage for electrons in the region $1.1<|\eta|<1.3$ is improved. For a better identification of γ's and π^0's, pre-radiators are now added to the central electromagnetic calorimeters. Of particular interest is the newly installed Silicon Vertex Detector (SVX). The SVX is able to resolve the secondary decay vertices from beauty decays. An enhanced rate of observed b quarks in the top candidate events above the rate expected from other sources will be a clear signal of top decays. The analysis of the first $p\bar{p}$ collision data shows that

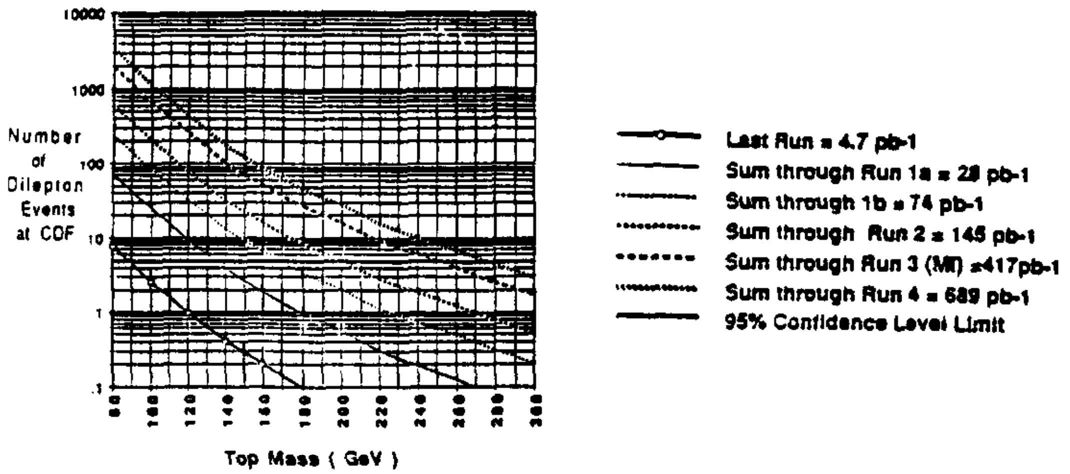

Figure 2: Number of expected dilepton events at CDF, as a function of the top mass, summing over the planned collider runs.

the SVX is performing very well.

2.2. The new detector D0

The D0 detector was expecially designed to study high P_t physics and therefore also to search for the top quark. It does not have a central magnetic field: this allows a compact highly segmented calorimeter, which is capable of an excellent measurement of energy of the electrons and jets and of missing E_t. The design energy resolution of the uranium+liquid argon calorimeter is $0.047 \oplus 0.439/\sqrt{E} \oplus 1.28/E$ for hadrons, $0.003 \oplus 0.162/\sqrt{E} \oplus 0.148/E$ for electrons (E in GeV) with a e/π ratio of about 1[4]. Electrons are identified using in addition the tracking system and transition radiation detectors. Muons are identified and momentum analysed in the magnetized iron toroids which surround the calorimeter. The muon coverage extends to $\Theta=3^0$ from the beam axis.

2.3. Expected Tevatron performances

In the 1992 run, thanks to the implementation of electrostatic separators and to antiproton source improvements, the Tevatron will be able to reach a luminosity of $5 \cdot 10^{30}$ pb^{-1}. This means that CDF and D0 by the end of 1993 should collect a total integrated luminosity of about 100 pb^{-1}. Beyond the 92–93 runs, the Tevatron luminosity is expected to increase further: during 1995 additional 100 pb^{-1} should be collected. We also hope that in 1998 the new Main Injector will become operational, providing again a substantial increase in luminosity. In figure 2 we show the number of expected dilepton events at CDF as a function of the top mass, summing over the planned collider runs.

3. New analysis tools

Not only the luminosity increases and the detector upgrades will increase the

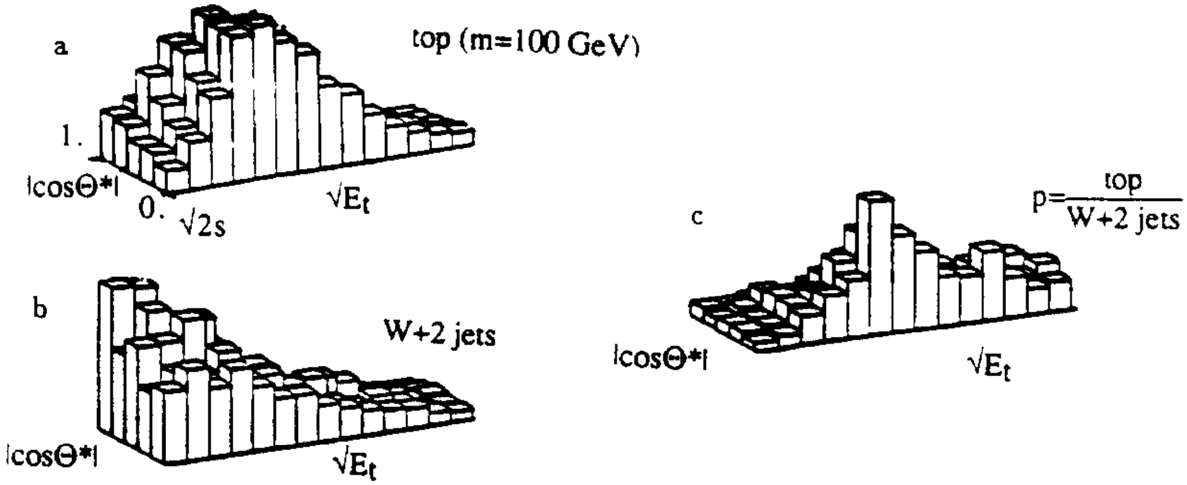

Figure 3: $\sqrt{E_t}$ versus $|\cos\theta^*|$ of jet$_1$ for: (a) a 100 GeV/c^2 mass top, (b) W+2 jets background, (c) ratio of the two distributions.

sensitivity for top. An important role can also be played by new analysis approaches. Several such new attacks to top are being developed at presents within CDF. We illustrate one of them in the following.

3.1. The study of the event structure

The transverse mass analysis in the single lepton channel doesn't work when $M_{top} > M_W + M_b$, since also the W from top decay becomes real. To overcome the problem of the overwhelming background for such values of the top mass one could look at the differences in the event structure between signal and background [5]. Many jets from QCD W+jets events come from initial state radiation or from gluon splitting. The jets from a $t\bar{t}$ decay are instead the decay products of a centrally produced heavy object.
In figure 3a,b,c we see an example of the variables which can be studied in order to separate top from background. Events with at least two large E_t jets (E_t>25 GeV) were selected. We plotted the $\sqrt{E_t}(\text{jet}_1)$ versus $|\cos\theta^*(\text{jet}_1)|$ for a 100 GeV/c^2 mass top (figure 3a) and for the W+2 jets background (figure 3b). In figure 3c we have the ratio of the two distributions. One observes a clear difference between signal and background.

To produce the above plots we used the Papageno Montecarlo [6]. At the time being to simulate the background we are using the Vecbos Montecarlo [7]. Vecbos is able to produce W+n jets events (n=1,2,3,4) using the correct matrix elements in lowest order.

3.2. Comparison of the W+jets Montecarlo with data

As an example we study W+3 jet events. The data are CDF central muon and electron samples from the 88–89 run. In addition to the lepton quality requirements we applied the following cuts:

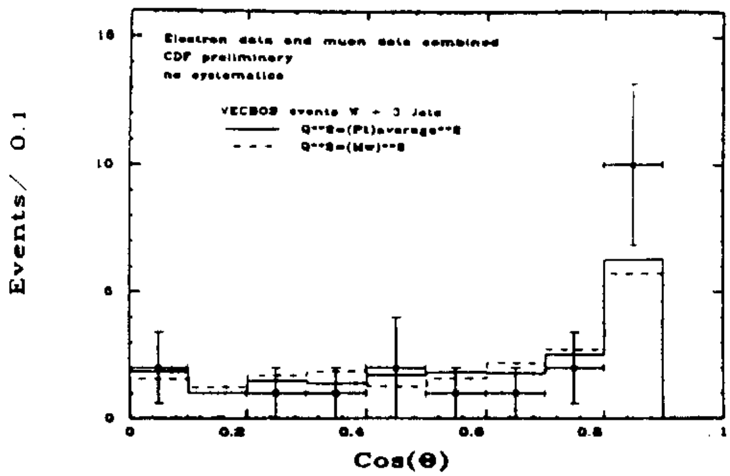

Figure 4: $|\cos\theta^*(\mathrm{jet}_3)|$ distribution for data and Vecbos events.

- Standard W identification cuts (large P_t, isolated e/μ, large missing E_t)
- Three and only three jets $E_t(\mathrm{jet})>15$ GeV
- Leading jet energy $E_t(\mathrm{jet}_1)>20$ GeV

In addition we require now that the jets should be in the central region. Let us call θ^* the angle between jet and proton direction in the rest frame of the event, having ignored the ν longitudinal momentum. We require $|\cos\theta^*(\mathrm{jet}_1)|<0.8$ and $|\cos\theta^*(\mathrm{jet}_{2,3})|<0.9$. These cuts are applied to disfavour jets from gluon bremsstrahlung from primary partons. We are left with 20 events only. In figure 4 and in figure 5 a comparison between data and Vecbos events for the $E_t(\mathrm{jet}_3)$ and $|\cos\theta^*(\mathrm{jet}_3)|$ distributions is shown. The predictions from Vecbos are shown for two different choices of the mass scale [1] q^2: $q^2=(M_W)^2$ and $q^2=<P_t>^2$. Further tightening the cuts to $|\cos\theta^*|<0.8$ would reject another factor 2 of the events. We know from Montecarlo studies that most top events would survive these cuts in $|\cos\theta^*|$, since jets from top decay tend to be central. There is no background subtraction applied to the sample shown in figure 4 and 5 , and there is no study of the systematic errors. Therefore no physics statements can be made at this point. However, data and predictions are in reasonable agreement, and this is true for all the three jet distributions.
Once the event structure of top and background will be fully understood, it will be possible to assign a top likelihood figure to each event.

4. Outlook

With the next runs the discovery range at the Tevatron should cover the full mass range within which Lep experiments indicate that top should be.

[1] The use of a lowest order matrix element means that one must choose a mass scale, q^2, for the strong coupling costant $\alpha_s(q^2)$. The effect from ignoring higher order contributions can be estimated by varying this mass scale.

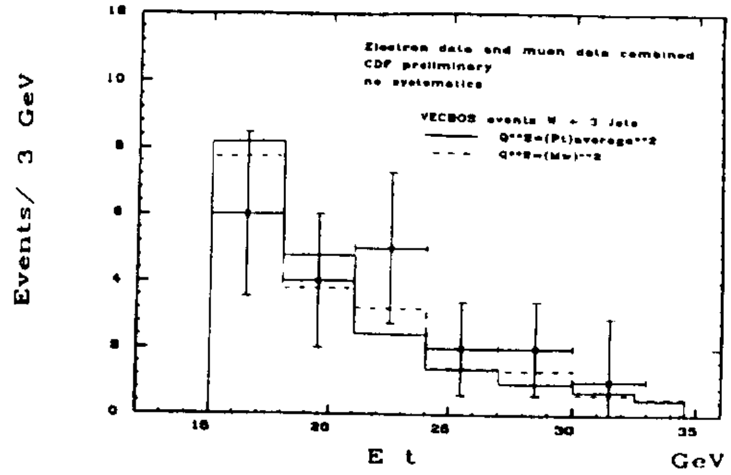

Figure 5: $E_t(jet_3)$ distribution for data and Vecbos events.

This means that in a few years either the top quark has been discovered, or the standard model will have to be questioned. Assuming that top will be discovered, a precise measurement of its mass would allow important tests of the standard model to be made. The top mass can be measured by observing the rate of top candidates. For example, if M_{top} is 150 GeV/c^2, we expect to measure M_{top} to within 10–15 GeV/c^2 by using the rate of observed dilepton events. However, the lepton+jets sample is probably the best channel to try to reconstruct M_{top}, because of the presence of only one neutrino among the decay products. B-tagging, as well as the study of the event structure, could help to handle difficulties like combinatorics or initial state radiation. Beyond measuring M_{top}, it will be extremely interesting to check that the top quark decays accordingly to the standard model. For example, rather large changes in the relative rate of single and dilepton final states from a $t\bar{t}$ event could indicate the existence of a charged Higgs.

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